Impulse and Momentum

Recall from Newton's 1st Law: *inertia* is the tendency of an object to keep on doing what its already doing, that is:

- either remaining stationary, or:
- travelling at a constant velocity.

We can describe the inertia of a moving object as its *momentum*. In essence, momentum is the quantity of motion possessed by an object. It is like the 'unstopability' of the mass, proportional to both the mass of a moving object and its speed, and described by the equation

$$\mathbf{p = mv} \qquad \text{with units being } \frac{\mathbf{kg\ m}}{\mathbf{sec}}.$$

For example, if a **1000 kg** car moves at **40 m/s**, its momentum is

$$\mathbf{p = mv = 1000(40) = 40\ 000}\ \frac{\mathbf{kg\ m}}{\mathbf{sec}}.$$

Impulse simply refers to a change in momentum, and is usually caused by a change in velocity, as described by

$$\mathbf{\Delta p = m\Delta v}.$$

For example, if a **200 kg** cart speeds up from **20 m/s** to **25 m/s**, the change in momentum of the cart is

$$\mathbf{\Delta p = m\ (v_f - v_i) = 200(25 - 20) = 1000}\ \frac{\mathbf{kg\ m}}{\mathbf{sec}}.$$

Since impulse involves a change in velocity, an acceleration and net force must take place.

From $\mathbf{F_{Net} = ma}$ and substituting $\mathbf{a} = \frac{\mathbf{\Delta v}}{\mathbf{\Delta t}}$ for acceleration,

we get $\mathbf{F_{Net} = m}\frac{\mathbf{\Delta v}}{\mathbf{\Delta t}}$ which simplifies to produce

$$\mathbf{F\Delta t = m\Delta v = \Delta p}.$$

In describing impulse, $\mathbf{F\Delta t}$ measures how long and how hard we must push to change a motion. Meanwhile, $\mathbf{m\Delta v}$ is the resultant change in the quantity of motion possessed by the mass.

An important note: impulse can be measured in both $\frac{\textbf{kg m}}{\textbf{sec}}$ or in **Newton-seconds** (**N-s**). However, momentum can't be measured in terms of force-time, because an object can travel at constant momentum without any net force acting on it. This means that units of force (Newtons) can't be used to help describe it.

Example #1: If a force of 250 N acts on a 50 kg mass for 10.0 seconds, what is the increase in velocity?

(see Momentum Ex 1 for answer)

Example #2: If a 2000 kg car is travelling 22 m/s along the highway and applies a force of 500 N for 12 sec to pass another car, what is the new velocity?

(see Momentum Ex 2 for answer)

Example #3: A 1000 kg car, travelling at 22 m/s strikes a concrete bridge support and comes to a complete halt in 0.50 seconds.

a) What average force acts on the car?
b) If the support was cushioned so that it took 3.0 sec. to stop, what is the force now?
c) Explain the significance of these two very different values.

(see Momentum Ex 3 for answer)

Example #4:

a) Calculate the impulse suffered by a 105 kg man who lands on firm ground after jumping from a height of 1.5 m.
b) What force would be exerted on the man if he bent his knees and absorbed the fall in 0.40 s ?

(see Momentum Ex 4 for answer)

Example #5: A 0.0030 kg bullet travelling with a velocity of 800. m/s is fired into a 0.50 kg box of sand that is at rest on a horizontal, frictionless surface. The bullet passes through the sand and emerges with a velocity of 200. m/s at the other side.

a) Find the impulse delivered to the sand.
b) Find the velocity of the box of sand after the collision.
c) If the bullet was inside the box for 0.020 s, find the average force exerted on the block.

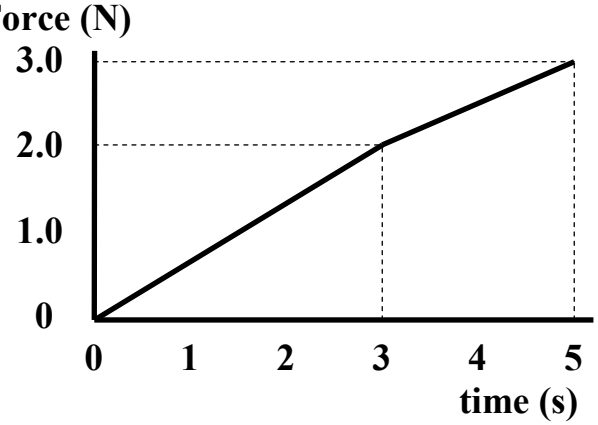
(see Momentum Ex 5 for answer)

Example #6: A 1.2 kg ball is thrown towards a brick building at 23 m/s. Find the impulse delivered to the ball if:

a) the ball shatters and goes straight through a window, slowing to 17 m/s.
b) the ball hits the brick wall and rebounds straight back at 19 m/s.

(see Momentum Ex 6 for answer)

Example #7: A changing net force acts on a 3.5 kg cart for 5.0 s, and is recorded on a Force-Time graph:



a) What is the total impulse?
b) What final velocity would the 3.5 kg mass have, travelling in a straight line, if its initial speed was 4.0 m/s?

(see Momentum Ex 7 for answer)